STRENGTH CHARACTERISTICS ANALYSIS OF STEEL SLAG HYDRATED MATRIX

A Project Submitted

In Partial Fulfillment of the Requirements

For the Degree of

Bachelor of Technology

In Civil Engineering

By

Amarendra Bhoi

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DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY ROURKELA

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Under the Guidance of

Prof. Asha Patel and Prof. Suresh Prasad Singh

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National Institute of Technology

Rourkela

CERTIFICATE

This is to certify that the thesis entitled, "STRENGTH CHARACTERISTICS ANLYSIS OF STEEL SLAG HYDRATED MATRIX" submitted by Shri Amarendra Bhoi in partial fulfillments for the requirements for the award of Bachelor of Technology Degree in Civil Engineering at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Date:

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Amarendra Bhoi Date:

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ABSTRACT

Iron and steel making slag are byproducts of the iron making and steelmaking processes. To date, these types of slag have been widely used in cement and as aggregate for civil works. A new product developed in Japan called “SSHM” (Steel slag hydrated matrix) which is made mainly from slag and absolutely free from natural aggregate. Steel slag hydrated matrix has the following features:

1. Made from 100% recycled resources.
2. Same strength performance as ordinary concrete.
3. Low alkaline dissolution.
4. Excellent wear resistance.
5. Excellent growth of biofouling organisms in marine environment.

This research work has the following objective

- To investigate different basic properties such as compressive strength, flexural strength etc. of Steel Slag Hydrated Matrix in comparison with ordinary concrete.
- To determine the mix proportion of fly ash, lime, ground granulated blast furnace slag, steel slag and water to achieve the required strength.

Strength characteristics analysis of Steel slag hydrated matrix

INTRODUCTION

Global warming and environmental destruction have become manifest problems in recent years, heightening concern about global environmental issues, and a changeover from the mass-production, mass-consumption, mass-waste society of the past to a zero-emission society is now viewed as important. The iron and steel industry produces extremely large amounts of slag as byproduct of the iron making and steelmaking processes, and is therefore continuing to develop slag reduction and recycling technologies and intermediate treatment technologies.

Iron and steel making slag are byproducts of the iron making and steelmaking processes. To date, these types of slag have been widely used in cement and as aggregate for civil works. There are two main types of slag, blast furnace slag and steelmaking slag. The former is produced as byproducts in the process of manufacturing pig iron in the blast furnace, and the latter is byproducts of steelmaking processes in the basic oxygen furnace (BOF), electric furnace, and so on.

As useful recycled materials, iron and steel making slag are mainly used in fields related to civil engineering, for example, in cement, roadbed material, and concrete aggregate. Their recycling ratio is close to 100%, making an important contribution to the creation of a recycling-oriented society. However, public works projects that are strongly related to recycled fields tend to be reduced recently and, moreover, other recycled materials, such as reused roadbed materials and fly ash, become competitor of slag in the fields. Thus, the development of new application technologies has become an urgent matter.

Recently, steel slag hydrated matrix (SSHM) has been developed as a construction material for reducing environmental problems. Its main ingredients are steel making slag, blast furnace slag powder which are by products of steel making process, slaked lime and fly ash.

This research work has the following objective

- To investigate different basic properties such as compressive strength, flexural strength etc. of Steel Slag Hydrated Matrix in comparison with ordinary concrete.
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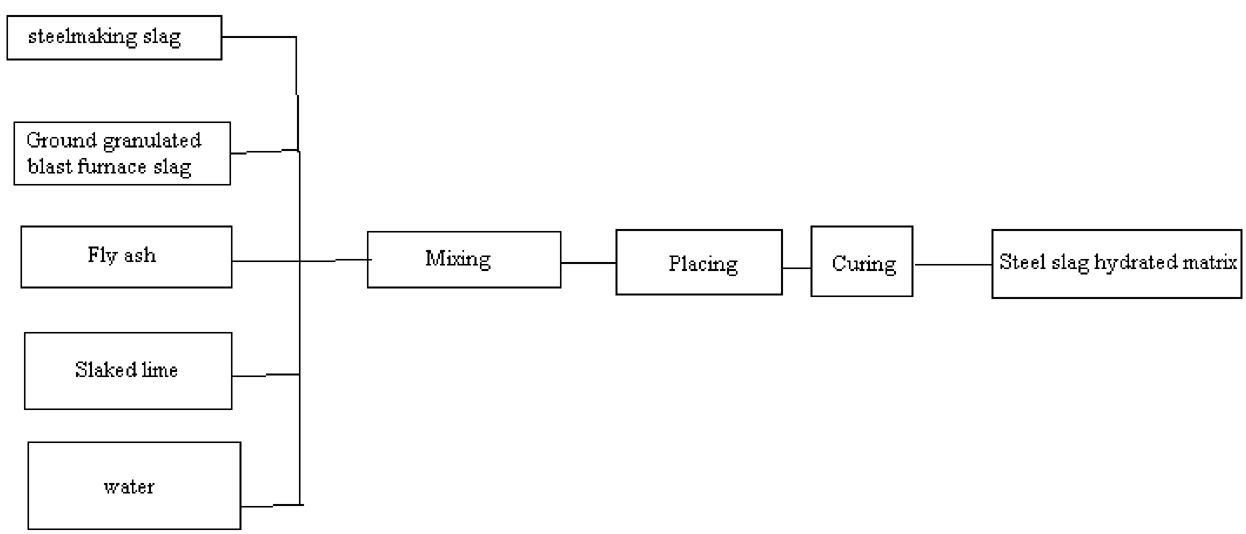
LITERATURE REVIEW

Development

Steel Slag Hydrated Matrix has been developed in Japan very recently. The JFE steel Group of Japan has developed many new technology and new materials from steel and blast furnace slag.

This is manufactured by basically the same process as the ordinary concrete. The material for steel slag hydrated matrix are steelmaking slag, ground granulated blast furnace slag(GGBS),fly ash, slaked lime, water and sometimes some admixture is also used. The replacement for the coarse aggregate is the steel slag, the replacement for fine aggregate is GGBS and the replacement for cement is the mixture of fly ash and slaked lime. Because this process is the same as with concrete, concrete manufacturing equipment can be used without modification.



The manufacturing process for steel salg hydrated matrix

EFFECT IN REDUCING ENVIRONMENTAL LOADS

The environmental problems nowadays are increasing in a steep rate. Global warming caused due to green house effect being the most serious amongst others. Concrete and its supplementary industry accounts for a larger portion of the CO_2 gas emission.

CO_2 emissions

The most serious problem with our industry is that it is a major CO_2 emitter causing global warming. With every ton of cement produced, almost a ton of CO_2 is emitted. About 0.5 tons comes from the decomposition of the limestone and the balance is generated by the power plant supplying the electricity to turn the kiln and ball mills to grind the cement plus the fuel burned to fire the kiln. All other generation such as operating ready mix trucks adds only a minor amount to the CO_2 emissions. In terms of conventional concrete mixtures (i.e. not using fly ash, slag or silica fume), about 480 kg of CO_2 is emitted per cubic metre of concrete or 20 kg of CO_2 per 100 kg of concrete produced. All of this amounts to about 7% of the total CO_2 generated worldwide. Enhanced efficiency is not likely to change this but replacement of some of the cement by a supplementary cementing material not associated with CO_2 emission can substantially reduce these emissions.

Particulate air emissions

Particulate emissions from the exhaust gas range from 0.3 to 1.0 kg/ton and much of this kiln dust is collected in fabric filter bag houses and then reintroduced into the kiln feed. It is normally very rich in sodium and potassium which have vaporization temperatures of only 883°C and 774°C respectively. In the past, before there was a concerted effort to capture the particulate emission, the sodium and potassium plume from cement plant chimneys settled over the countryside where it helped to combat acid rain. Now it is mainly carried out in the clinker stream where it creates problems with alkali aggregate reaction.

Visual pollution

Visual pollution resulting from quarries used to gain raw material for cement production or for obtaining sand and gravel can be sculptured to meet the natural topography and when abandoned can be planted with vegetation that can make them blend in with the natural surroundings. Unfortunately most quarries have a very long life and any attempt to sculpture the topography for a visual effect is counter-productive to the efficiency of the quarrying process. The most effective end use might be for educational or recreation purposes with special attention being paid to public safety.

Steel slag hydrated matrix, which is manufactured using all waste materials can be a great asset in consuming all wastes. As its material components are only by products it does not contribute directly to the adverse effect on environment. SSHM is less energy intensive and does not emit heat so it helps in reducing the green house effect.

A trial calculation of the reduction of natural aggregate consumption and CO_2 emissions was made assuming that 1 million tons of steel making slag per year is used in steel slag hydrated matrix. The results are shown below: (JFE technical report No .8, oct 2006)

- Reduction of natural aggregate consumption: 1,320,000 tons per year.
- Reduction of CO_2 emission by avoiding use of cement: 116,000 tons per year.

The CO_2 reduction is equivalent to 0.1% of the reduction target set for Japan in the 3rd session of the Conference of the parties to the United Nations Framework Convention on climate change (UNFCCC-COP3).

PROSPECTIVE USE:

- This matrix can be used where concrete of lower grade is used like concrete for mud matting, backfill etc.
- This material felicitates the growth of biofouling organisms which, with normally form on break water blocks in marine environment. The steel slag hydrated matrix is an excellent habitat for the growth of marine organisms. So SSHM may be used in marine structures.
- Its density is greater than the normal concrete, giving it higher stability against waves when used in breakwater blocks in coastal areas.

EXAMPLE OF APPLICATION

Artificial stones and cover blocks using SSHM were manufactured and placed in a shore protection repair project at JFE Steel's West Japan Works (Kurashiki) between Sept. 2000 and Sept. 2002. A continuous type mixer was used in mixing the materials, and the cover blocks were manufactured by pouring into forms and curing in the same manner as with ordinary concrete blocks. The artificial stones were manufactured by breaking SSHM which had been cast in the yard into large pieces. An example of the condition of work in the shore protection repair project is shown in Photo. In this project, the installation area covered a total length of 652 m fronting the Inland Sea. First, 36 000 t of artificial stones were deposited from the sea surface by a grab ship, and finishing forming was performed by divers. A crane ship then placed 776 cover blocks weighing approximately 10 t each. It was possible to handle the SSHM artificial stones and cover blocks in the same manner as natural stones and concrete blocks.

exection of port and harbour construction using SSHM blocks(JFE Technical Report No.8,oct 2006)

EXPERIMENTAL PROGRAM

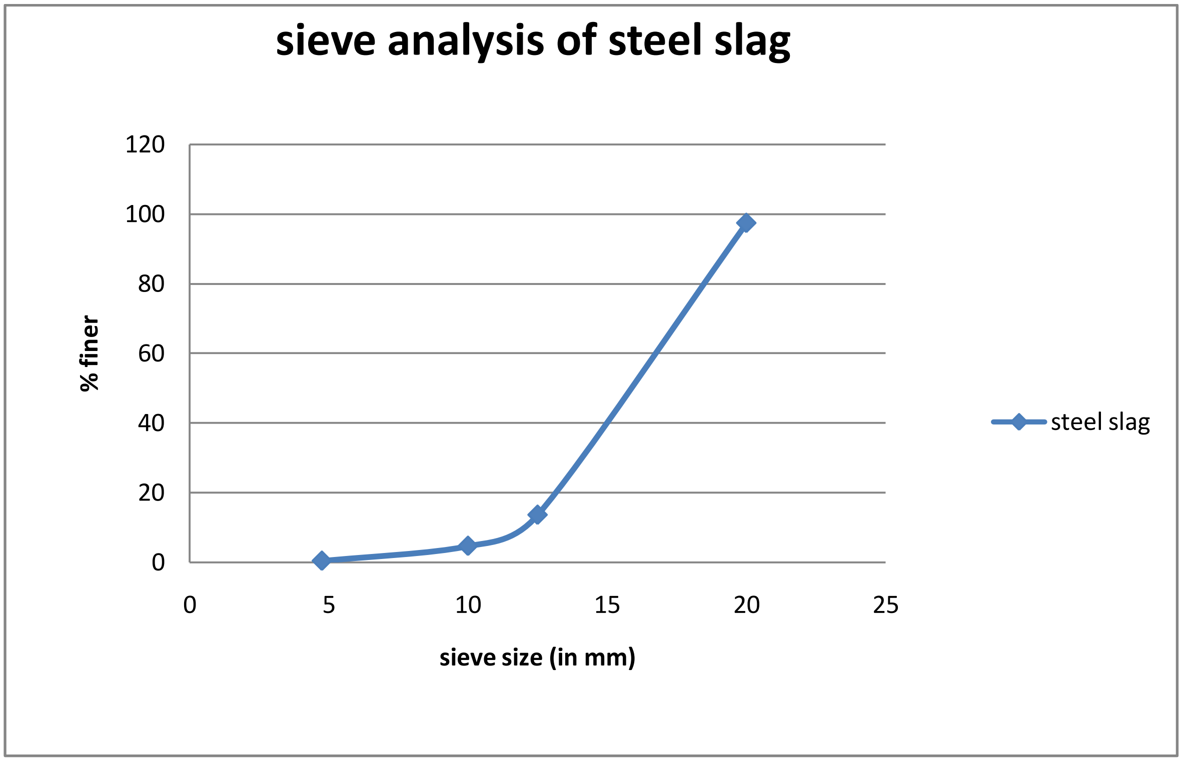
Materials

The materials for steel slag hydrated matrix are steel making slag, ground granulated blast furnace slag (GGBS), fly ash, slaked lime, water, and a small amount of admixtures. Cement and natural aggregates are not used.

Steel slag

This is the main ingredient of steel slag hydrated matrix (SSHM). In our research program we have used the locally available steel slag. It was procured from the Rourkela Steel Plant, Rourkela. This material replaces the coarse aggregate in normal concrete. The different physical and chemical properties of steel slag are given below.

Steel slag

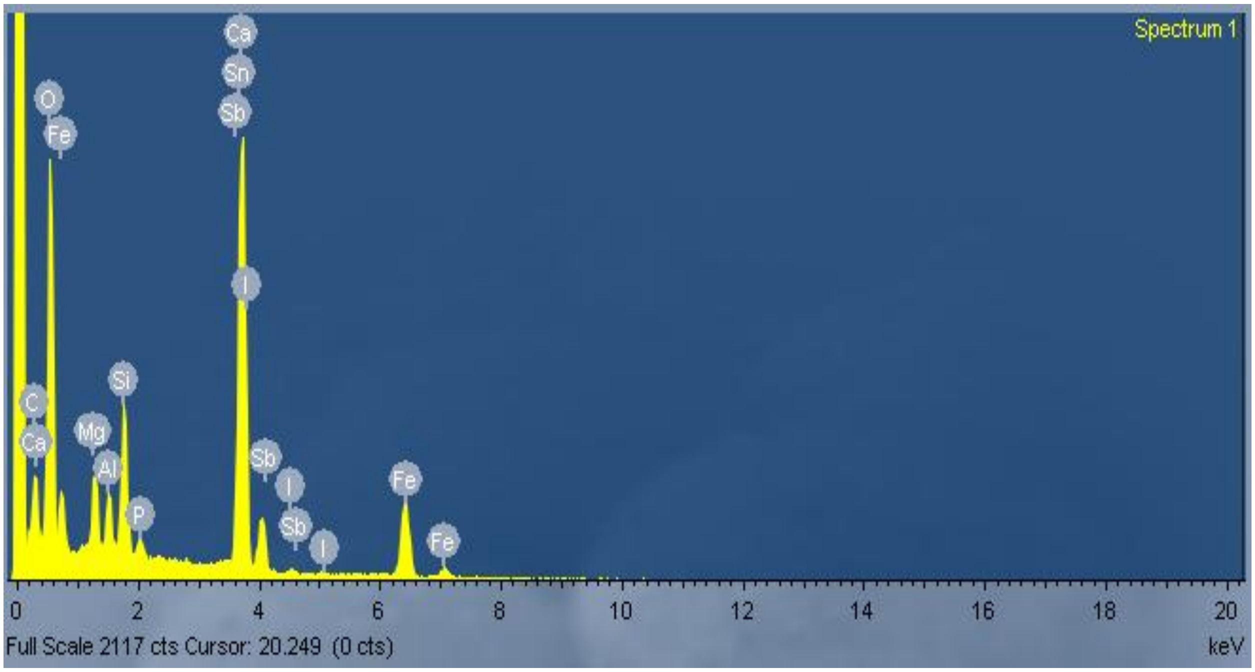


Chemical composition of steel slag

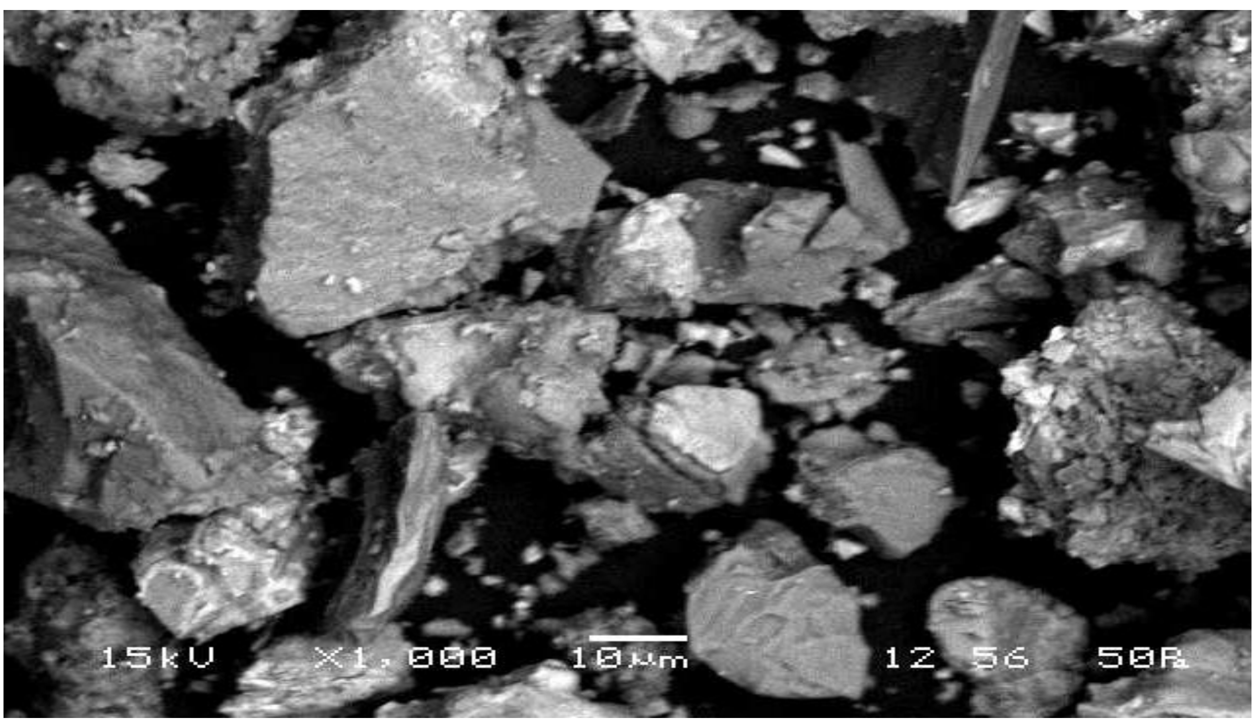
constituent	Composition (%)
Total Fe	18
CaO	34
SiO_2	15
MgO	2
Al_2O_3	4
P_2O_5	5
MnO	4

Physical characteristics steel slag

characteristics	value
Specific gravity	2.98
Water absorption	0.6%
Los Angeles Abrasion	23%



Microscopic pattern of steel making slag

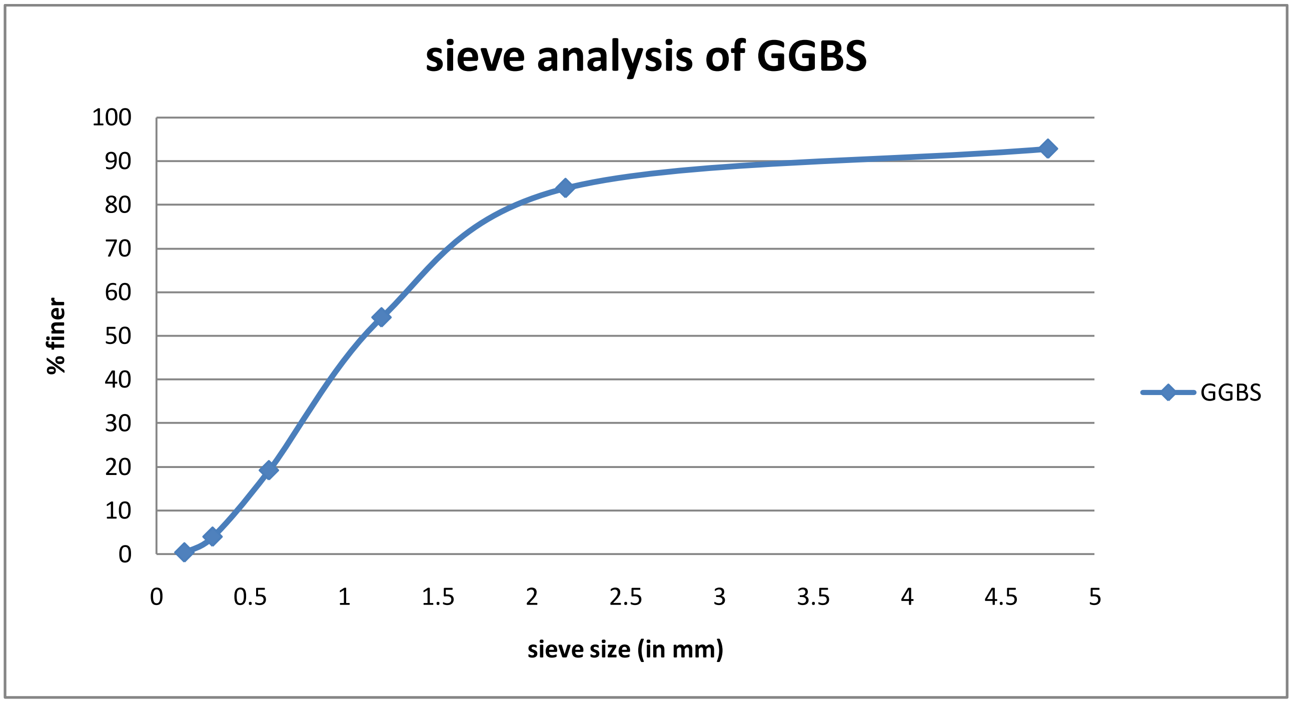


SEM analysis of Steel making slag at 1000 magnification

Ground granulated blast furnace slag (GGBS)

This is also one of the most important ingredients of steel slag hydrated matrix. It replaces the fine aggregate in normal concrete. It has high binding properties. In our project we have used the GGBS procured from Rourkela Steel Plant, Rourkela. Different physical and chemical properties of GGBS are given below.

Ground granulated blast furnace slag

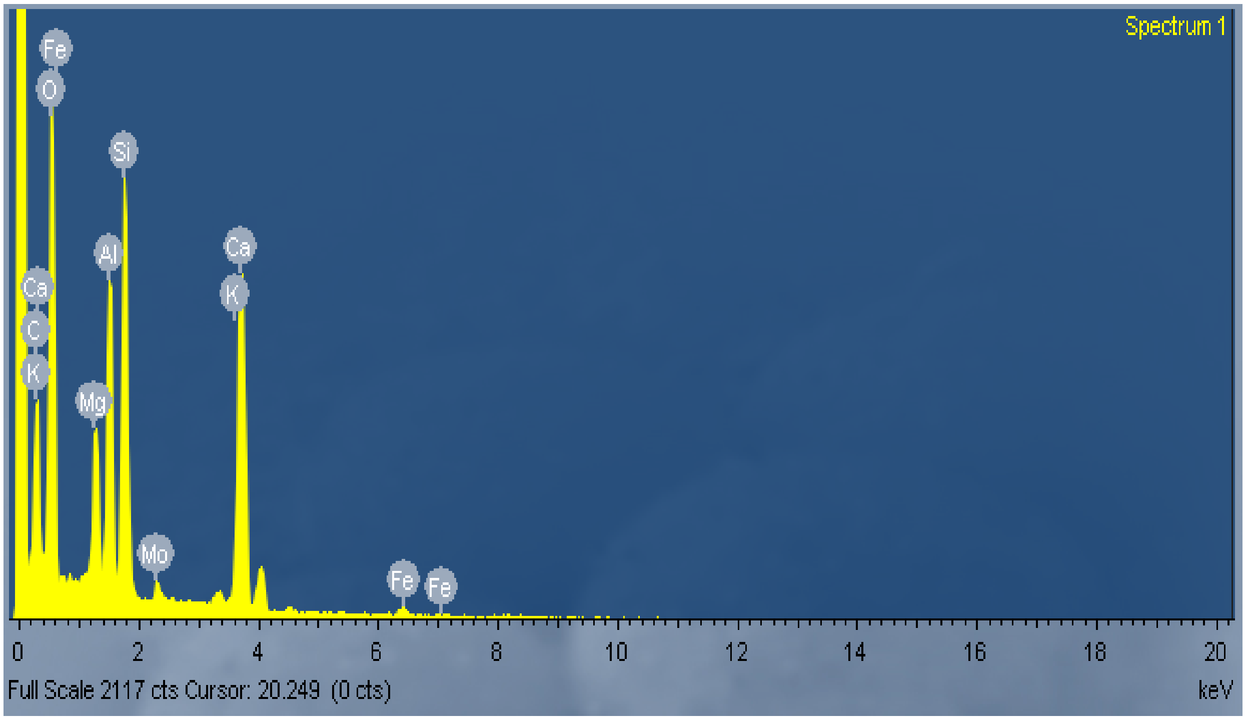


Chemical composition of GGBS

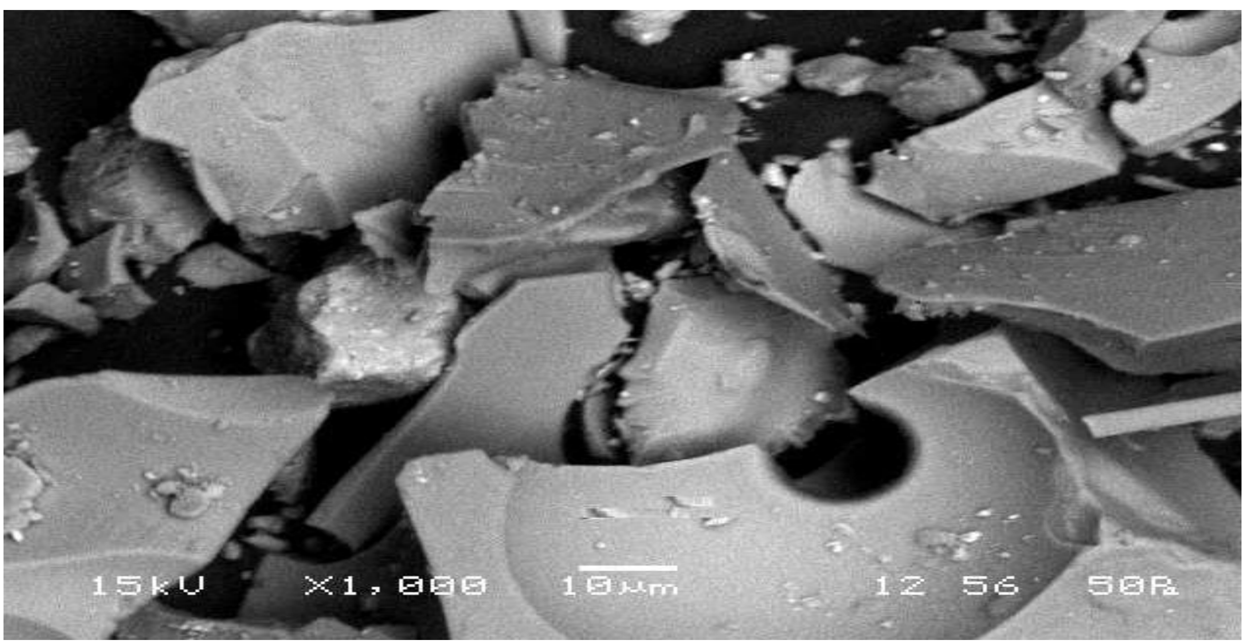
constituent	Composition (%)
Total Fe	0
CaO	42
SiO_2	33
MgO	7
Al_2O_3	13
P_2O_5	0
MnO	0

Physical characteristics of GGBS

characteristics	value
Specific gravity	2.17
Water absorption	1.4



Microscopic pattern of GGBS



SEM analysis of GGBS at 1000 magnification

Fly ash

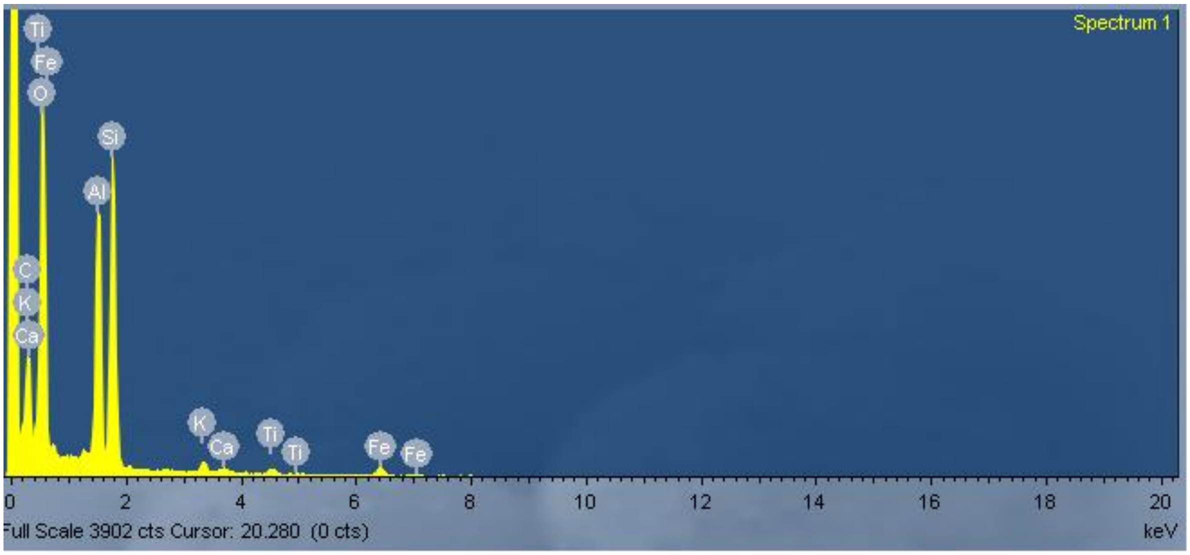
This along with lime replaces the cement in normal concrete. We procured this from OCL,Rajgangpur. Different physical and chemical properties of fly ash are given below.

Chemical composition of fly ash

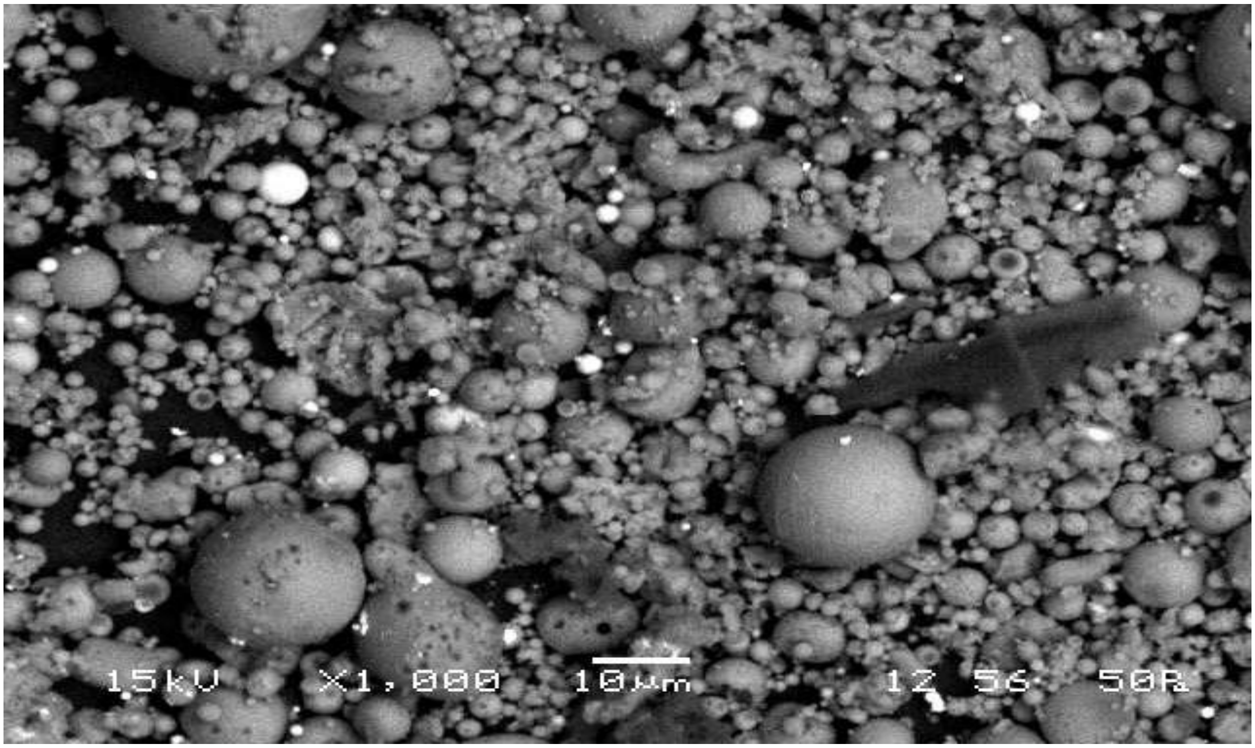
constituent	Composition (%)
Total Fe	5
CaO	1
SiO_2	63
MgO	0
Al_2O_3	27
P_2O_5	0
MnO	0

Physical characteristics fly ash

characteristics	value
Specific gravity	2.20
Moisture content	0.02%



Microscopic pattern of Fly ash



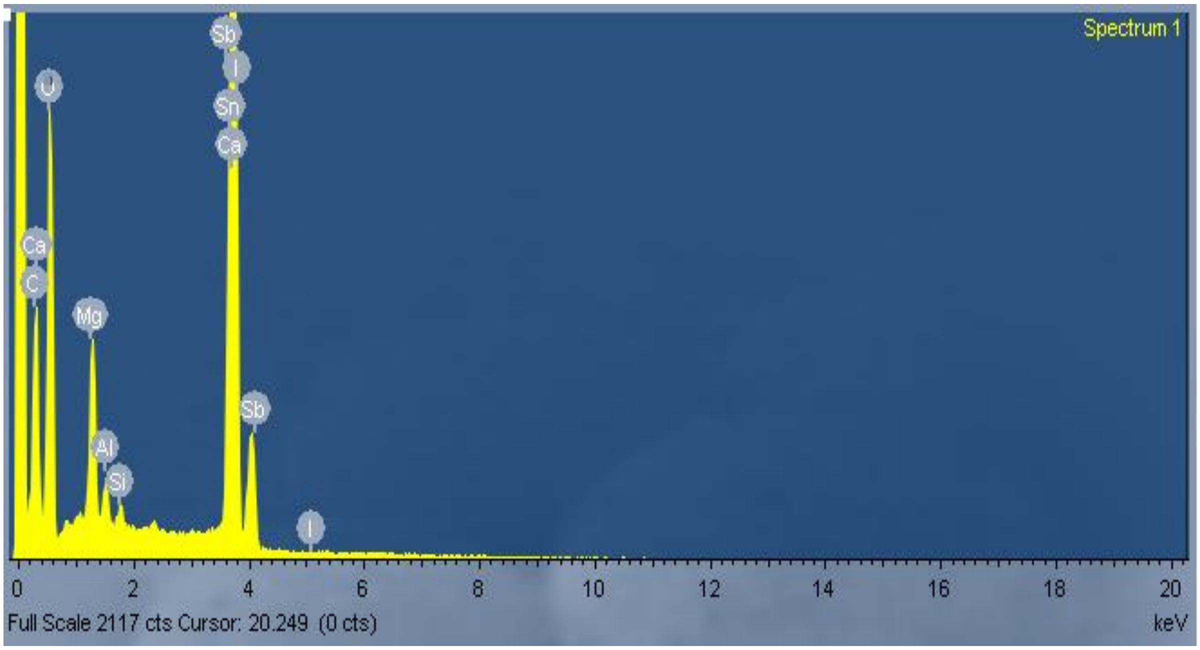
SEM analysis of Fly ash at 1000 magnification

Slaked lime

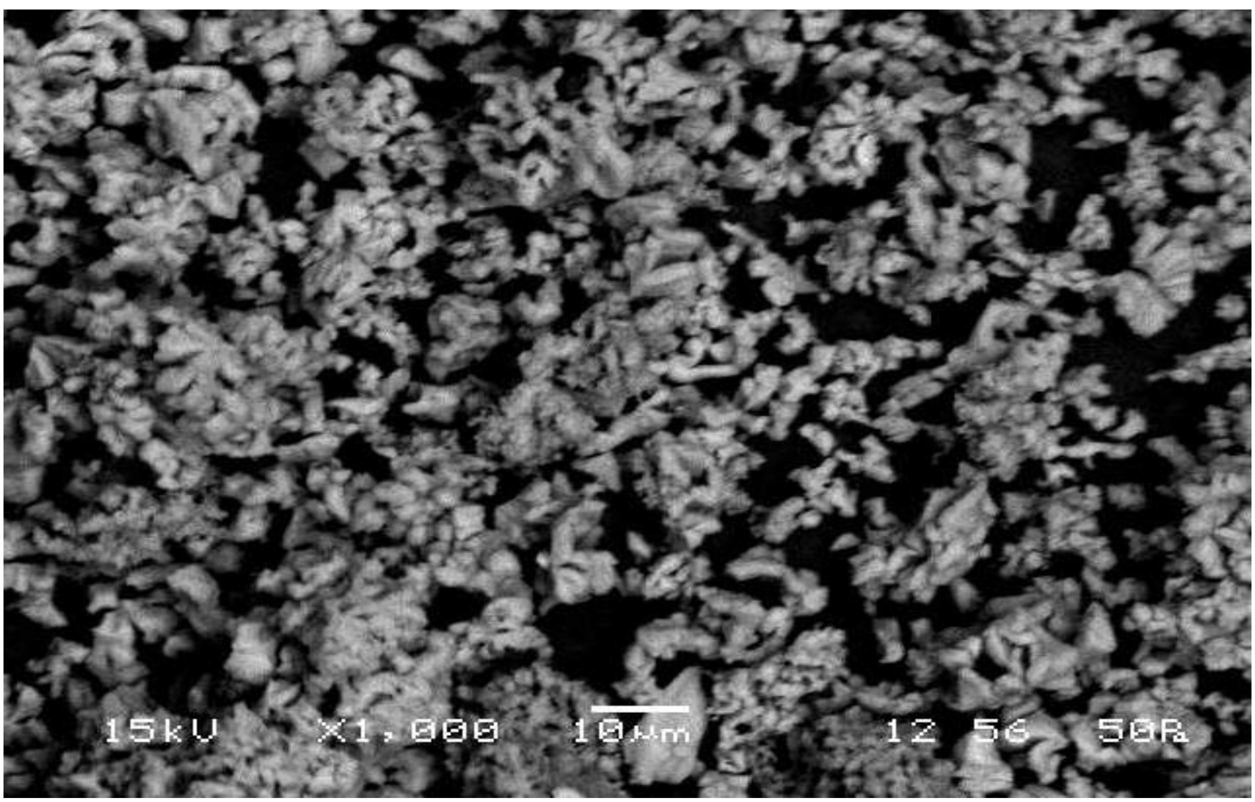
Slaked lime along with fly ash replaces cement in normal concrete. In our project we have used the locally available lime. This in SSHM acts as an activator. The different physical and chemical properties of slaked lime are given below.

Physical characteristics of slaked lime

Specific gravity: 2.87



Microscopic pattern of slaked lime



SEM analysis of slaked Lime at 1000 magnifications

Mix proportions

To get the consistency and setting times of the powder (; lime + fly ash), six different types of mix were prepared by varying the lime and fly ash contents from 100% to 20%.

For the mortar test the ratio of powder and GGBS (Ground granulated blast furnace slag) was taken to be 1:2 and six different types of specimen were prepared by varying the lime content.

To prepare the SSHM (steel slag hydrated matrix), the mix proportion of powder, GGBS and steel slag was taken as 1:1.5:3. Here also six different types of specimen were prepared by using different lime and fly ash content.

A specimen of normal concrete with the mix of 1:1.5:3 (cement: sand: aggregate) was prepared to compare with the new SSHM. The w/c ratio was taken to be 0.6.

Specimen preparation

To determine the consistency and setting times of powder of different lime and fly ash content, specimen were prepared by taking required lime and fly ash contents and adding water. The specimens were prepared in a mould of size confirming to IS code.

The specimens for mortar test were prepared by mixing one part powder with two parts of GGBS. Water was added with respect to the consistency of their proportion of lime and fly ash. The specimens were prepared in a cubical mould of 50 mm side and compacting it using vibrator.

The steel slag hydrated matrix was prepared by taking one part of powder, 1.5 parts of GGBS and three parts of steel slag. Water was added with respect to the consistency of the proportion of lime and fly ash component. No other admixture like super plasticizer was used. The specimens were prepared in a cubical mould of 150mm size. Table vibrator was used to vibrate the specimens.

Curing

The curing process was done after one day of sample preparation. The specimens were dipped inside a water tank, which was located in a room. So the curing temperature was less than room temperature.

RESULTS AND DISCUSSION

Consistency and setting time

Lime (%) + Fly ash (%)	Consistency (%)	Initial setting time	Final setting time
100+0	67	1h 30m	25h 08m
80+20	58	1h 25m	25h 03m
65+35	56	1h 48m	23h 48m
50+50	53	1h 40m	27h 30m
35+65	45	1h 10m	10h 47m
20+80	43	1h 35m	11h 02m

There is no definite trend in setting times for different mix proportion of lime and fly ash which is visible from the above table. But both the initial and final setting times of these mixes are higher than the normal portland cement. The higher setting times may be due to the slow reaction of the mix with water. From the above table it is noticeable that the consistency decreases with decrease in the lime content.

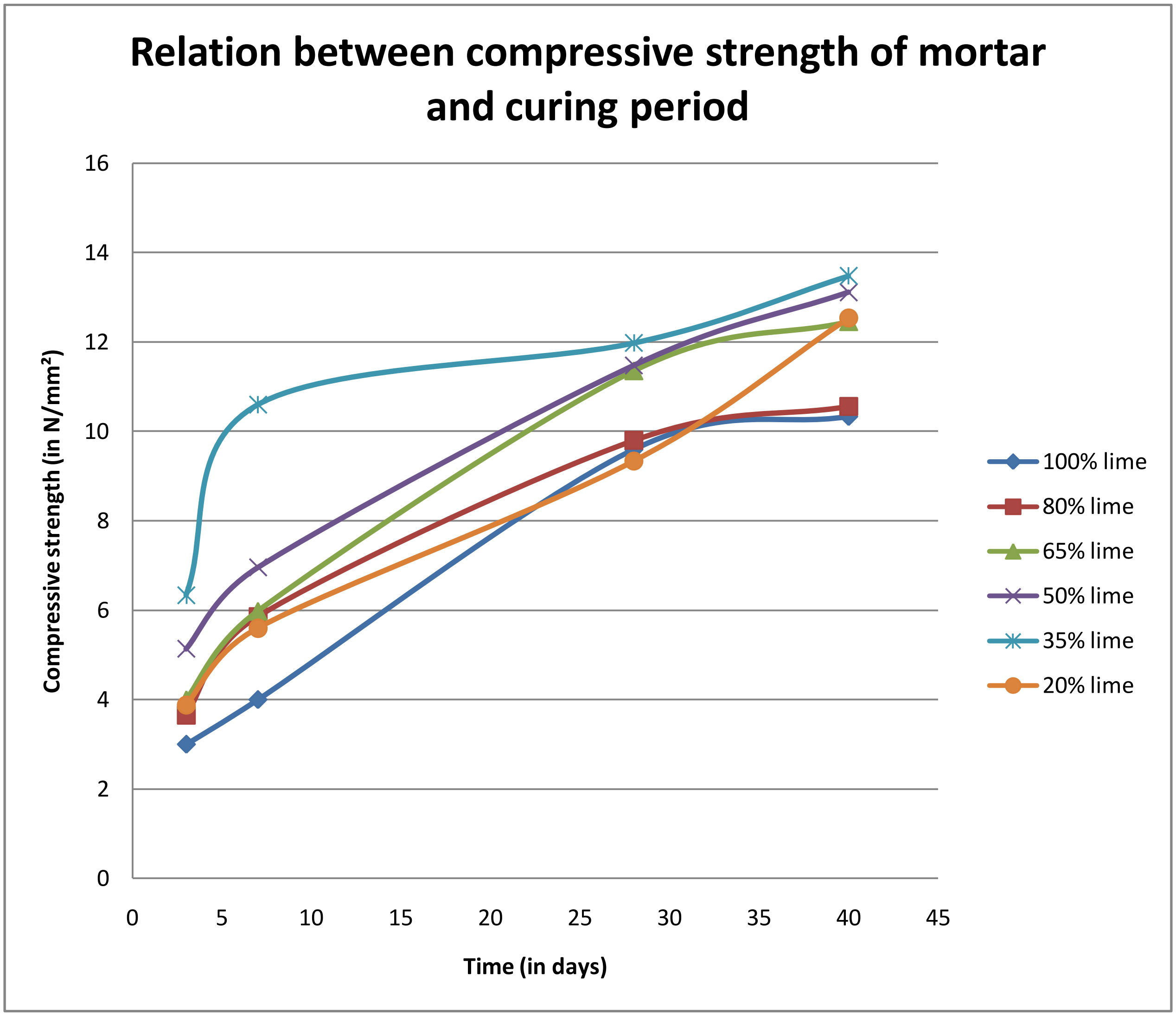
Mortar Test

Compressive strength of GGBS mortar

P: powder (lime + fly ash), w: water

(Lime + fly ash): GGBS =1:2

Lime (%) +Fly ash (%)	w/p	3 Days Compressive strength (N/mm^2)	7 Days Compressive strength (N/mm^2)	28 Days Compressive strength (N/mm^2)	40 Days Compressive strength (N/mm^2)
100+0	0.67	3	4	9.6	10.34
80+20	0.58	3.66	5.86	9.8	10.56
65+35	0.56	4	5.98	11.36	12.36
50+50	0.53	5.14	6.96	11.48	13.12
35+65	0.45	6.34	310.6	11.98	13.48
20+80	0.43	3.88	5.6	9.34	12.54



From above graph it is concluded that the mortar exhibit low early strength but shows considerable increase in strength with curing period. The low early strength may be due to the slow reaction between the powder and the water. But the reaction continues for a longer period hence more gain of strength with age. It is little inconclusive in which way it changes with respect to different powder mix (lime+ fly ash). But the mortar with 35% lime content gives the maximum compressive strength.

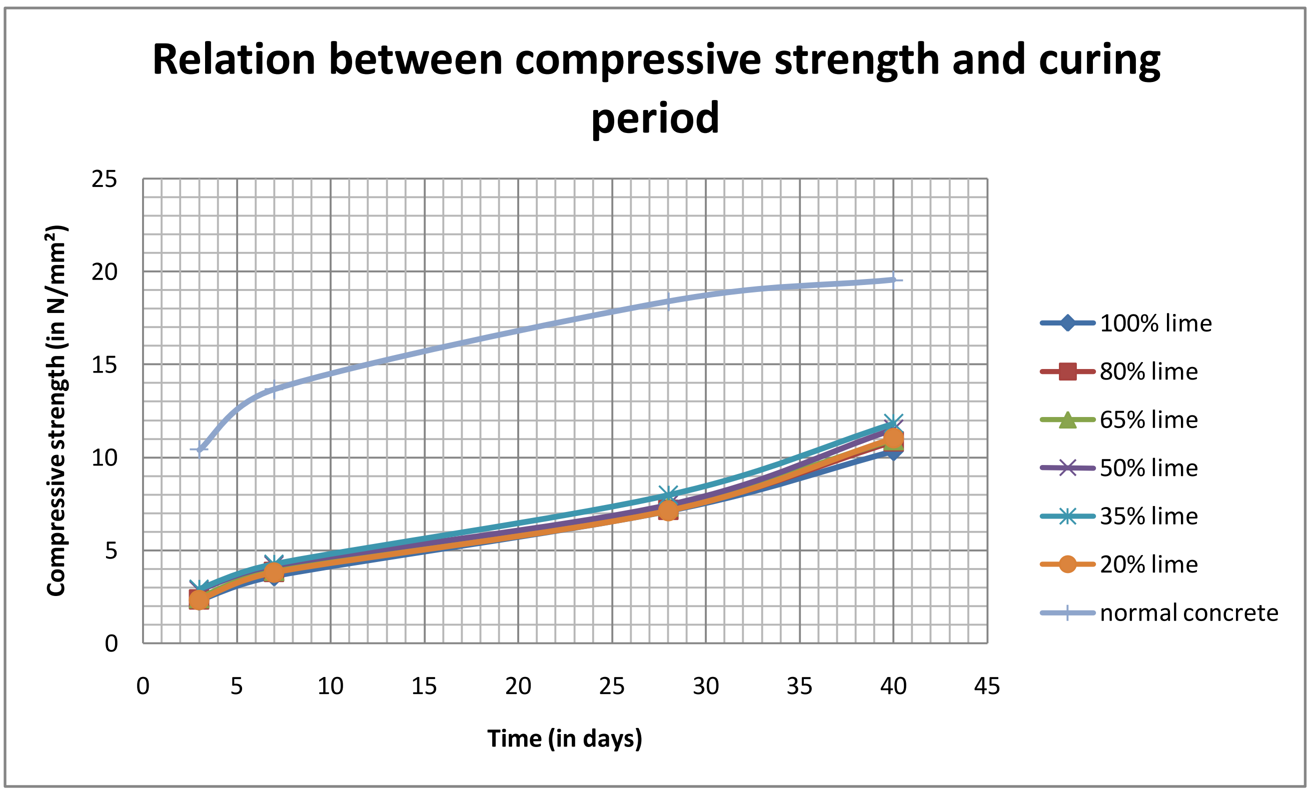
Compressive strength

Compressive strength of **SSHM**

P: powder (lime + fly ash); w: water

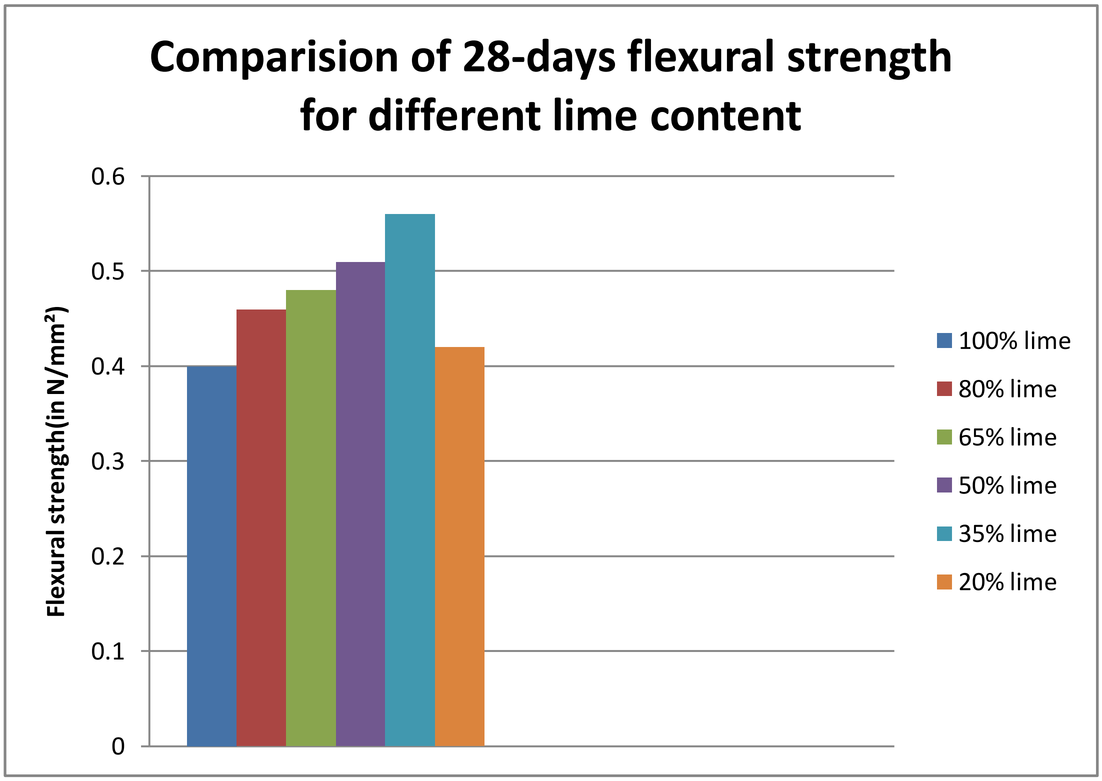
(Lime + fly ash): GGBS: steel slag=1:1.5:3

Lime (%) +Fly ash (%)	w/p	3 Days Compressive strength (N/mm²)	7 Days Compressive strength (N/mm²)	28 Days Compressive strength (N/mm²)	40 Days Compressive strength (N/mm²)
100+0	0.67	2.31	3.62	7.12	10.34
80+20	0.58	2.38	3.85	7.18	10.86
65+35	0.56	2.45	3.92	7.38	10.95
50+50	0.53	2.86	4.18	7.45	11.52
35+65	0.45	2.92	4.26	7.98	11.83
20+80	0.43	2.34	3.82	7.14	11.04
Normal concrete	0.65	10.42	13.68	18.40	19.56

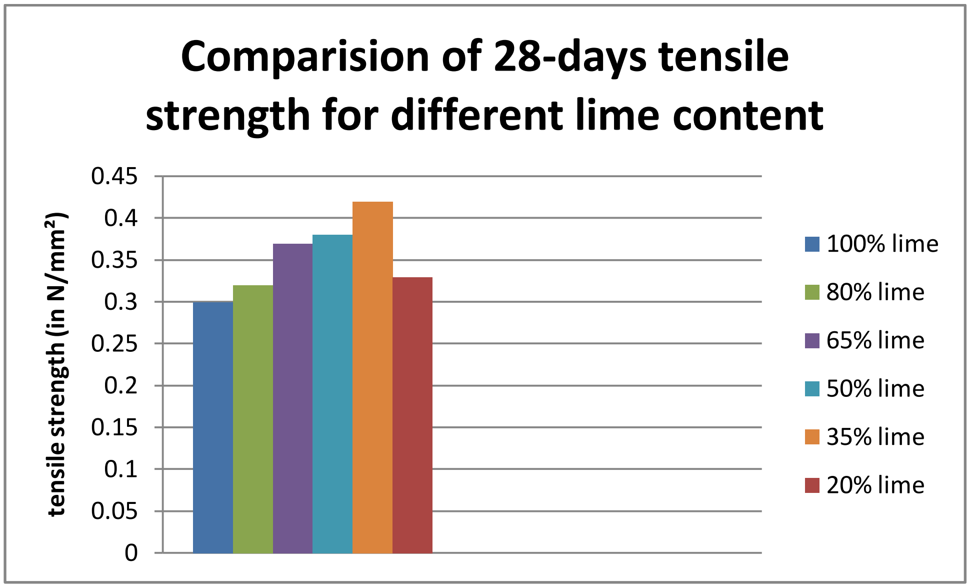


From the above graph it is evident that the strength of SSHM is less than the normal concrete. But the fact which is worth noticing that it is not at par with the strength shown by the GGBS mortar. It gives the idea that there might be some fault with the steel slag. Here also the low early strength is due to the fact that the reaction between the powder and water is slow. But the reaction continues for longer period and hence there is considerable gain of strength after 28 days. There is very little gain in strength in case of normal concrete. Here also though there is no clear idea which way the proportion of lime and fly ash affect the strength. But the matrix with 35% lime gives the highest strength.

Flexural strength

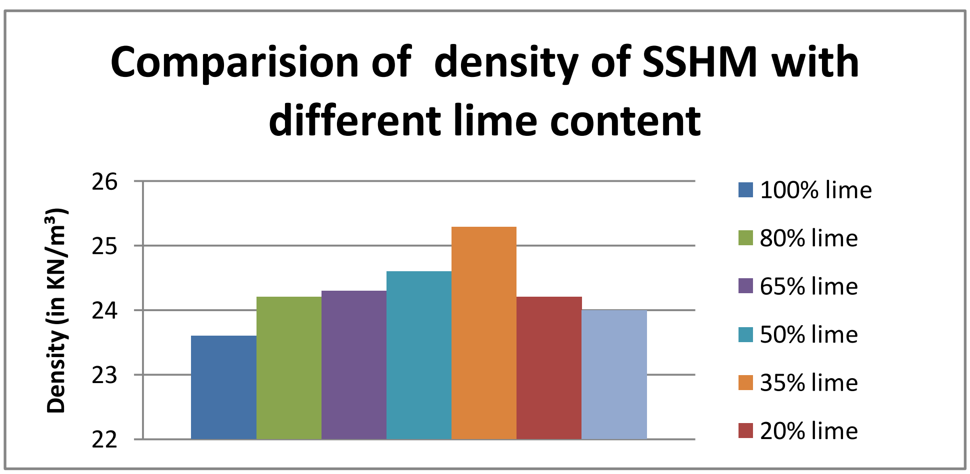


Tensile Strength



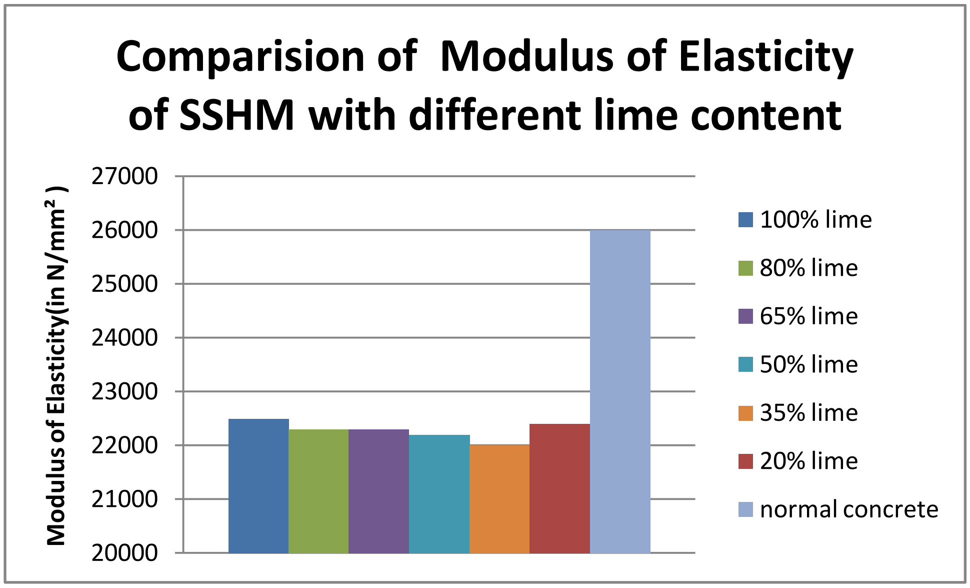
Tensile strength of SSHM is very less compared to the ordinary concrete.

Density



It is evident that the density of steel slag hydrated matrix is more than the normal concrete. So the blocks made from it are more stable and resist more transverse load. It is therefore used in marine environment to counteract the sea waves.

Modulus of Elasticity



We can see from the above diagram that modulus of elasticity of normal concrete is more than that of SSHM. So SSHM may be used for dynamic loading like earthquake and vibration due to machines. Nowadays there is a lot of work is being to generate ductile concrete and SSHM definitely attracts the attention towards it.

REASON FOR LOWER STRENGTH

Some other researchers have found the compressive strength of SSHM in the range of 20 N/mm^2 to 30 N/mm^2 after 28 days of curing (JFE technical report No .8, oct 2006). But in our case we have got compressive strength in the range of $6N/mm^2$ to $8N/mm^2$. This lower strength of SSHM may be due to the following reasons:

- The steel slag was full of foreign particles like coal, burnt soil lumps and some other materials .These have swelled after coming in contact with water and consequently creating cracks in the SSHM.
- There were too much dust particles in the steel slag covering the surface of it hence opposing the cohesion and interlocking between the slags and subsequently resulting in low strength.
- There were foreign particles in the GGBS. Moreover it was not stored in a confined container rather was exposed to the atmosphere hence decreasing the activity of GGBS.
- The slaked lime was impure with less CaO content.
- Though the maximum size of steel slag was 20mm it was a poorly graded one.
- Use of high water powder ratio which could have been reduced using some admixtures like superplasticizer.

CONCLUSION

The new material called "Steel Slag Hydrated Matrix", consisting of mainly of steel making slag, ground granulated blast furnace slag, fly ash, and water matrix has a number of excellent features, including the following:

1. Made from 100% recycled resources.
2. Considerable strength as ordinary concrete.
3. Excellent wear resistance and other physical properties.
4. Low alkaline dissolution.
5. Excellent growth habitat for biofouling organism in marine environment.
6. Economical.
7. Little adverse effect on environment.

The steel slag hydrated matrix has been used as material for artificial stone and cover blocks, confirming its ease of use in construction with conventional techniques. Test also confirms that it has low impact on the ecological system. A trial calculation shows that this material will make substantial contribution to reducing natural aggregate consumption and CO_2 emission.

SCOPE FOR FUTURE STUDIES:

The research work on steel slag hydrated matrix is still limited. But it promises a great scope for future studies. The research work may be done on following directions:

- To get a rational mix proportion of steel slag, GGBS and powder to get required strength.
- The effect of admixture like superplastizer on SSHM.
- The effect of SSHM on steel reinforcement.
- As the elastic modulus of SSHM is lower than normal concrete it can be used to prepare ductile concrete to be used for dynamic loading.
- The long term gain of strength of SSHM may be investigated.
- Research work may be done to see the durability aspect of steel slag hydrated matrix.

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